

EFFECT OF DISCHARGES FROM KIMBERLY-CLARK LTD.
ON THE WATER QUALITY OF JACKFISH BAY,
LAKE SUPERIOR, 1981

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December 1986

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FOREWORD

The information presented in this report was derived from one of a series of investigations conducted by the Ministry under the 1983 Lake Superior Intensive Year program, as a contribution to the International Joint Commission's Great Lakes International Surveillance Plan.

The 1983 survey was conducted to update information collected in 1974 on conventional water quality parameters and to provide baseline information concerning the identity and concentration of organic pollutants in pulp and paper discharges.

The publication of the report has been delayed. The mill was destroyed by fire in the fall of 1981 shortly after this survey was completed. During the reconstruction of the mill improvements were made to the pollution control equipment which could alter the quality of the effluent and the quality of the water in Jackfish Bay.

BACKGROUND

Peninsula Harbour

NE shore of Lake Superior with town of Marathon on the SE shore. Main discharges are a bleached kraft pulp mill complex and the sewage treatment plant. Both are located in Marathon.

Contaminants in sediments and water column include mercury, PCB's, iron, chromium, nickel, dieldrin, HCB and oxychlordan.

There has been severe contamination of sediments by mercury with levels of (0.06-27.0 mg/kg) recorded. Fisheries have been affected and recent surveys indicate lake trout with average mercury concentrations of 0.28 mg/kg. Fish advisory warnings have been issued and lake trout under 65 cm in length may be consumed while those in excess of 65 cm are placed in a limited consumption category.

Previous studies indicate localized contamination by PCB's (23-690 ug/kg). However more recent data (1985) show lake trout levels for PCB of 0.42 mg/kg. Large lake trout have occasionally been found to exceed the guideline of 2.0 mg/kg set by Health and Welfare Canada.

Suggested sampling area: around Jellicoe Bay.

Jackfish Bay

One major point source of toxic discharges - the Kimberly Clark Mill at Terrace Bay which discharges into Blackbird Creek. Consequently the Moberley Bay area is particularly contaminated.

A study in 1981 found levels of mercury, cadmium, copper, nickel and zinc which exceeded guidelines (Table 6, Figure 6). Sediment contamination was also evident. Levels of chromium, iron, copper, oil and grease, COD and total phosphorus exceeded the disposal guidelines throughout most of the Bay (Figure 7).

Mercury levels in the water column of up to 3.3 ug/l were found (Provincial Water Quality Objective is 0.2 ug/l). A fish advisory has been issued due to mercury contamination and white lake trout greater than 45 cm are allowed only limited consumption while whitefish and cisco are suitable for unlimited consumption.

Organic contamination was also detected. PCB levels of up to 0.93 mg/kg in sediments. A 1983 study detected PCB's in young - of - the - year spottail shiners of 80 ug/kg (the Great Lakes Water Quality Objective if 100 ug/kg.

Suggested sampling area: Moberley Lake, the arm near Moberley Bay (Jackfish Bay) and the area immediately downstream of Terrace Bay itself.

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ulated in countries surrounding both systems. More recent investigations in both systems reveal that DDT levels in fish and birds has fallen but that PCBs in some areas remain a significant problem (44). The same kind of scenario is true for heavy metals. While this provides reason for encouragement, the fact remains that hundreds of different hazardous chemicals have been detected in the waters of the Baltic and the Great Lakes, and there is a justified concern that some of these mutagens and/or carcinogens will cause genetic damage, birth defects, or cancer in humans.

In the Great Lakes the severity of the toxic problem is greatest in coastal waters where human activities are concentrated. For example, 38 of the 42 "areas of concern" in the Great Lakes (Figure 6) are known to exceed guidelines for protection of aquatic life or human health for one or more toxic substances (37). Advisories that alert the public about which sizes and taxa of fish are contaminated are in effect for most of the 42 "areas of concern." In the Great Lakes it has taken nearly two decades to collect enough information about contaminants on a system-wide basis

to begin to mount a balanced plan to remediate toxic contamination. As with conventional pollutants, the plan must deal with contaminants at the source since they are largely beyond practical control once they enter the environment. Unfortunately, for some contaminants (e.g. PCBs), a major source is now the sediments, and a new jargon phrase has entered our language (i.e. in-place pollutants). However, the need for ecological credibility and economic accountability, let alone political acceptability, requires that remediation of toxic contamination be cast in a system context. Such an approach is now being developed and tested in one locale in the Great Lakes, Green Bay, Lake Michigan (45-47).

Green Bay was recognized as being seriously degraded as early as the late-1920s. Intensive remediation was not initiated until the early-1970s and then only in the form of reducing BOD loadings to the major tributary entering Green Bay, the Lower Fox River. Since 1970, USD 338 million have been invested in wastewater-treatment facilities by both municipalities and industries along the Lower Fox River. The impact of new treatment plants was

rapid and impressive. Dissolved oxygen levels (summer average) in the nearshore areas of the bay jumped from $1.6 \text{ mg} \cdot \text{L}^{-1}$ in 1970 to 8.1 in 1982. Phosphorus reduction programs aimed at municipal sewage-treatment plants resulted in a total phosphorus reduction in Green Bay of 30 to 40 percent.

Even with improvements in the water quality of the Fox River and the Bay, many uses remained impaired. Algal blooms continued to occur in spite of reductions in phosphorus concentrations; waters remained turbid and swimming beaches closed. Submergent macrophytes did not recover, and waterfowl populations continued to decline (Figure 4). Worse, PCB levels in the carp (*Cyprinus carpio*) resulted in closure of the fishery; and the carp population, which is blamed for destruction of fish habitat, remains dominant in the fish community. Walleye (*Stizostedion vitreum*) stocked in the mid-1970s survived and grew but were contaminated by PCBs and placed under a "fish consumption advisory" which warned anglers against eating designated size classes of this and other fish species. Fish-eating birds were found to have birth deformities

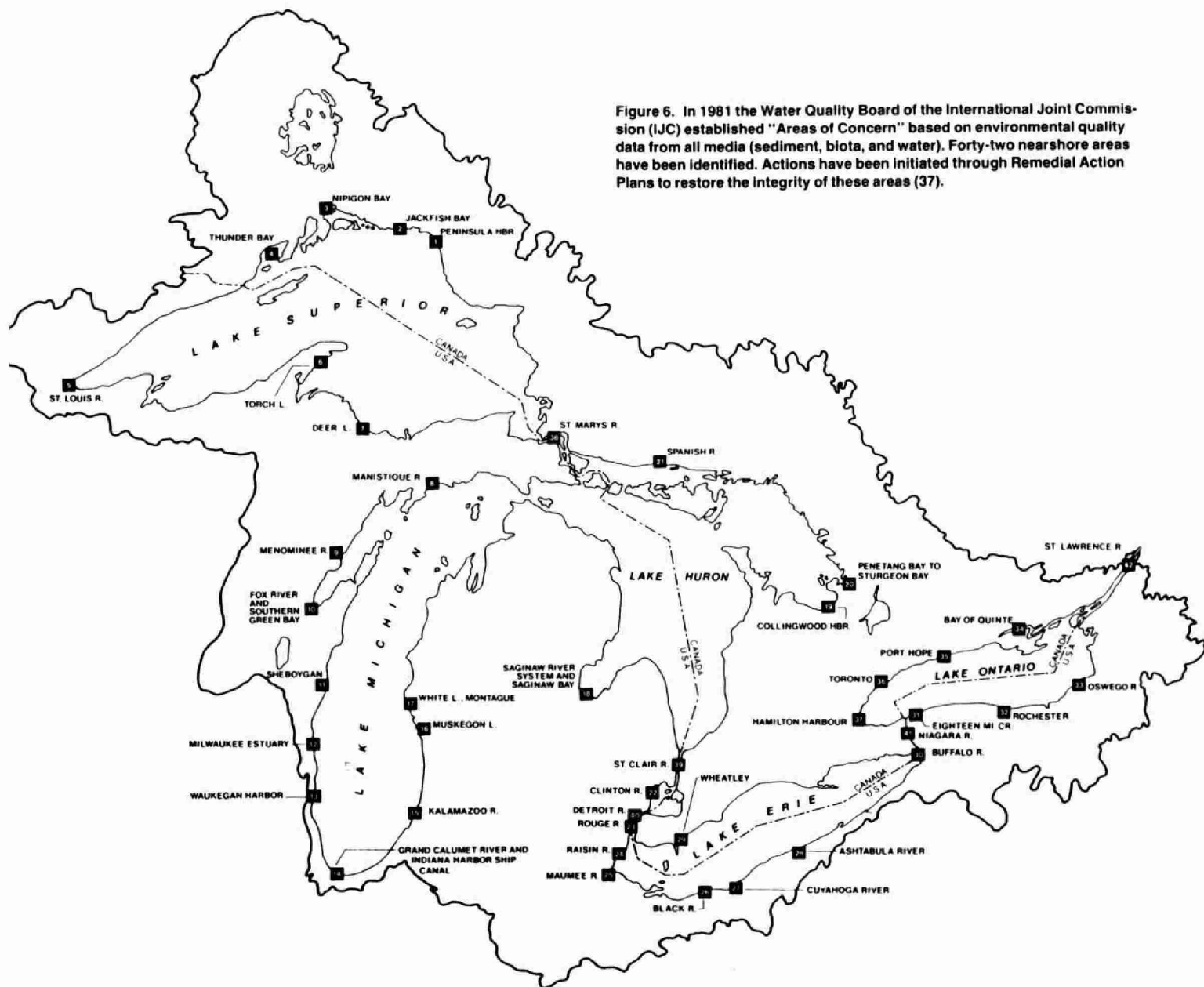


Figure 6. In 1981 the Water Quality Board of the International Joint Commission (IJC) established "Areas of Concern" based on environmental quality data from all media (sediment, biota, and water). Forty-two nearshore areas have been identified. Actions have been initiated through Remedial Action Plans to restore the integrity of these areas (37).

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ACKNOWLEDGEMENTS

This study was initiated and designed by Ms C. Cherwinsky of the Great Lakes Section, Ontario Ministry of the Environment, under the supervision of Dr. M.A. Zarull of the same Section. This study was funded in part by Environment Canada under the terms of the Canada-Ontario Agreement on Great Lakes Water Quality.

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1. EXECUTIVE SUMMARY

In 1981 the Ontario Ministry of the Environment conducted a survey of the water quality and sediments in Jackfish Bay, Lake Superior. Jackfish Bay is the receiving water of effluents from the Kimberly-Clark Ltd., a bleached kraft pulp mill located in Terrace Bay. The mill discharges wastes into the headwaters of Blackbird Creek which flows for approximately 15 km and passes through one lake on the way to Jackfish Bay. The purposes of the 1981 survey were to update information collected in 1973 on conventional parameters in the water and sediments and to provide baseline data on the identity and concentration of organic contaminants for which historical information was limited or non-existent.

For the purposes of this survey samples collected in Blackbird Creek in April and May, 1981, were regarded as effluent samples. The effluent comprises over 90% of the stream flow in the upper reaches of Blackbird Creek. The Provincial Water Quality Objectives (PWQO) for the protection of aquatic life and recreation were exceeded by fecal coliform bacteria, metals including cadmium, copper, lead and zinc, and organics including reactive phenolics, pentachlorophenol and PCBs. Fecal coliforms exceeded the PWQO by the largest amount and would require a 1:50,000 dilution in the receiving water to meet the PWQO. The actual dilution for the Kimberly-Clark effluent in Jackfish Bay has been estimated to be 1:20 at about 6 km from the point of discharge.

The water quality survey of Jackfish Bay was conducted twice, once in June and once in September. During the June survey the mill was operating at levels which were fairly typical of 1981. However, the conditions during the September survey were unrepresentative as the mill had shut down for maintenance just before the survey was conducted and insufficient time had elapsed following start-up for effluent to pass through Blackbird Creek to Jackfish Bay.

The PWQOs for reactive phenolics, fecal coliforms and mercury were exceeded over an extensive area in June. Sampling for metals other than mercury was restricted to one location near the mouth of Blackbird Creek where the PWQOs for cadmium, copper, nickel and zinc were exceeded. The concentration of some organic compounds near the mouth of Blackbird Creek indicated a potential fish toxicity problem as abietic acid and isopimaric acid exceeded the 96-hour LC₅₀ concentrations for trout reported in the literature. Guaiacol was also detected in this area at concentrations which taint fish flesh and cause odour problems in water, while the concentration of pentachlorophenol exceeded the PWQO.

When the results of the June 1981 survey were compared to those of 1970 there was no indication of any improvement in the water quality of Jackfish Bay. This assessment was based on conventional parameters only, as historical data on organic pollutants were lacking.

On the basis of the comparison between the data collected in June with that collected in September following the mill shutdown, it can be anticipated that a rapid decrease in the concentration of several conventional parameters will follow improvements in effluent quality. The detection of toxic concentrations of abietic acid in September suggests that this may not be true of all compounds.

The results of the sediment survey were indicative of a degraded environment with levels of chromium, iron, copper, oil and grease, chemical oxygen demand, total phosphorus, total Kjeldahl nitrogen, zinc, cadmium, mercury, and PCBs exceeding the Spoils Disposal Guidelines in parts of Jackfish Bay. The elevated concentrations of metals and other parameters are of concern because of the potential for uptake of contaminants by benthic organisms and accumulation in the food chain, and because of the potential for release of contaminants from the sediments contributing to future water quality impairment.

2. RECOMMENDATIONS

1. Jackfish Bay should be re-surveyed in the near future as the mill was destroyed by fire in the fall of 1981, after the present survey was completed. During the reconstruction of the mill improvements were made to the pollution control equipment which could alter the quality of the effluent and the quality of the water in Jackfish Bay. Future surveys should incorporate effluent sampling coincident with water quality sampling in the Bay, more extensive sampling of metal concentrations and more extensive sampling of organic compounds to allow the area of impact to be defined. The associations of contaminants with the finer particles in the sediment suggests that use of a stratified sampling design would improve our ability to detect changes in sediment quality. For the same reason, the sedimentation rate in Jackfish Bay should be determined. This would allow the amount of sediment deposited since the previous survey was conducted to be quantified and assist in the interpretation of the results.
2. Due to the ambiguity in fecal and total coliform tests, some samples in future surveys should be analyzed for the presence of Klebsiella pneumoniae, a coliform not normally found in large numbers in human wastes. This will improve assessment of potential health hazards due to fecal contaminants.
3. The health risks of Klebsiella pneumoniae should be assessed due to the abundance and ubiquity of this bacterial species in pulp and paper mill effluents.
4. The identification of a large number of organic compounds in Jackfish Bay for which little is known of their ecological significance (see Tables 8 and 9 of this report) suggests a need for research in this area as a step towards establishing Provincial Water Quality Objectives.

3. INTRODUCTION

In 1981 the Ontario Ministry of the Environment conducted a survey of the water quality and sediments in Jackfish Bay on Lake Superior. There were two main objectives of the survey, the first of which was to update information collected in 1973 (Kinkead et al no date) concerning the extent of impairment of the water and sediments in the Bay resulting from waste discharges from Kimberly-Clark Limited, a Kraft pulp mill operating in Terrace Bay. Between the 1973 and 1981 surveys the mill was expanded and several operational procedures were changed to improve effluent quality. Although an improvement in effluent quality was anticipated to reduce the concentration of some parameters in the sediments and receiving water, it could not be presupposed that the concentration of all parameters would be reduced. Some could be expected to increase or remain unchanged as a result of their persistent and cumulative nature.

The second objective of the survey was to provide baseline information concerning the identity and concentration of contaminants in the water and sediments for which historical information was limited or non-existent. The historical information consisted largely of measurements of BOD (biochemical oxygen demand), DO (dissolved oxygen) and other conventional parameters. Since pulp mill effluents may contain a large number of organic substances, the list of parameters was expanded to include pesticides, phenols, chlorinated organics and resin and fatty acids (Brownlee and Strachan 1977). Organic compounds are important to identify and quantify, since some are known carcinogens and mutagens (Nestmann et al 1980, Kringstad and Lindstrom 1984), while others have been shown to taint fish flesh (Shumway and Palensky 1973) and cause taste and odour problems in drinking water.

4. DESCRIPTION OF THE STUDY AREA

Jackfish Bay is located approximately 225 km northeast of Thunder Bay. It consists of two small bays which join to form an outer expanse of open water (Figure 1). The small bay on the western side is called Moberly Bay. It receives the effluents from the Kimberly Clark Terrace Bay Pulp Mill. The maximum water depth in Moberly Bay is over 20 m. To the east lies Tunnel Bay, which is generally deeper than Moberly Bay and which has been used as a control area during previous studies of the aquatic impacts of the Kimberly-Clark mill. Weather data collected at Terrace Bay from May to October in 1972 and 1973 indicate that winds blow predominantly from the south (Beak Consultants Ltd. 1974).

The facilities in the Kimberly-Clark Terrace Bay mill at the time of the 1981 survey consisted of two mills, one of which was constructed in 1948 and renovated during the period 1975 to 1978, and the other of which was constructed during the period 1975 - 1977. The mills produce bleached kraft pulp, most of which is exported to finishing mills in the United States. The first mill on the site had an initial design capacity of 275 ADTPD (air dried tons/day). Production from this mill steadily increased to a high of 435 ADTPD in 1975 when the plans for expansion and renovation were initiated. Following construction of the second mill, production in the first mill was to be reduced to 350 ADTPD to reduce effluent loadings. The second mill was designed with a capacity of 900 ADTPD (Beak Consultants Ltd. 1974).

Process water for the mill and domestic water for the Town of Terrace Bay are obtained through a common intake on Lake Superior. The combined water requirement increased from 27 mgd before the mill expansion to approximately 38 mgd afterwards. Although less than 2% of the total supply is used for domestic purposes, all the water is chlorinated.

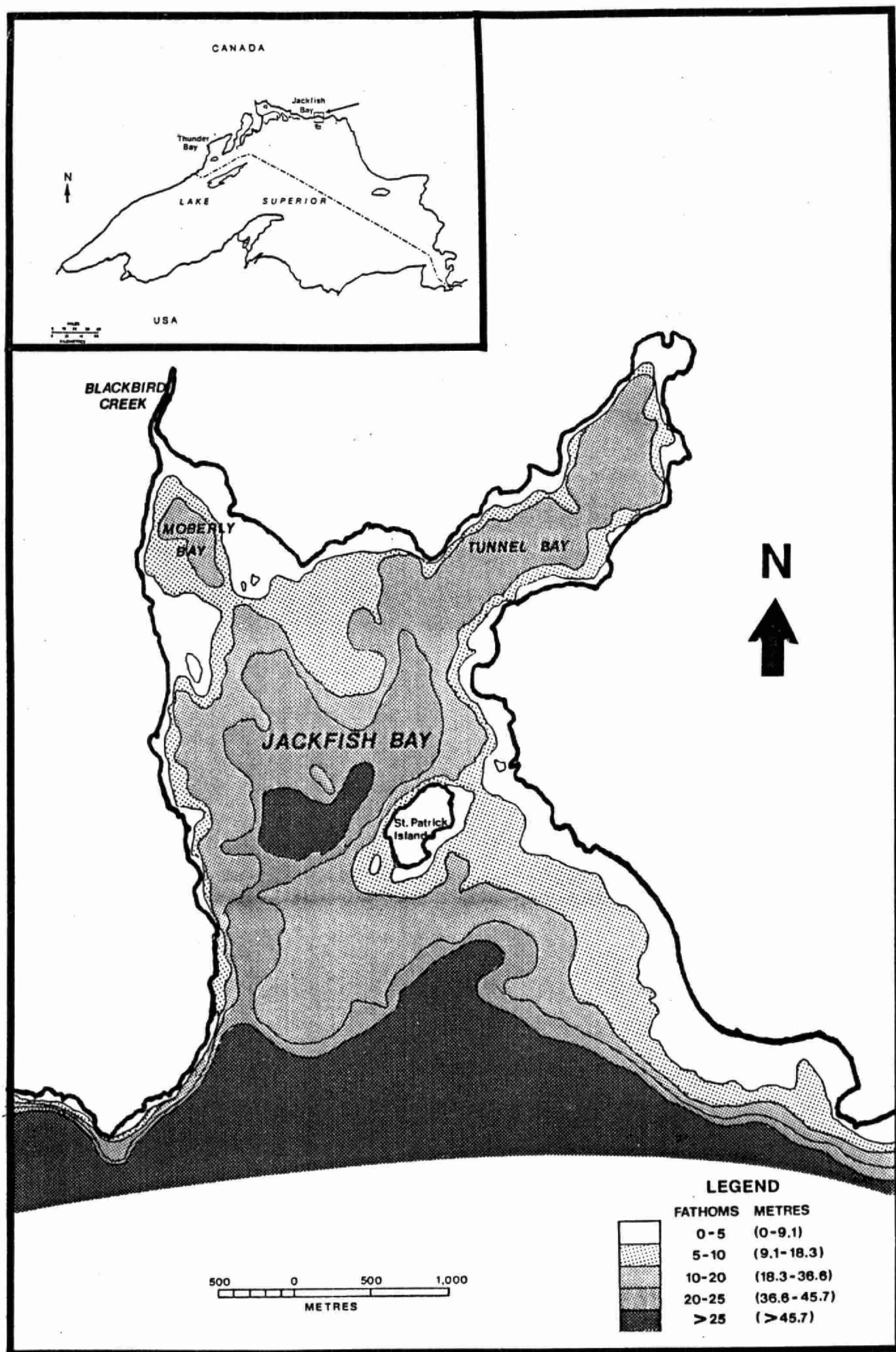


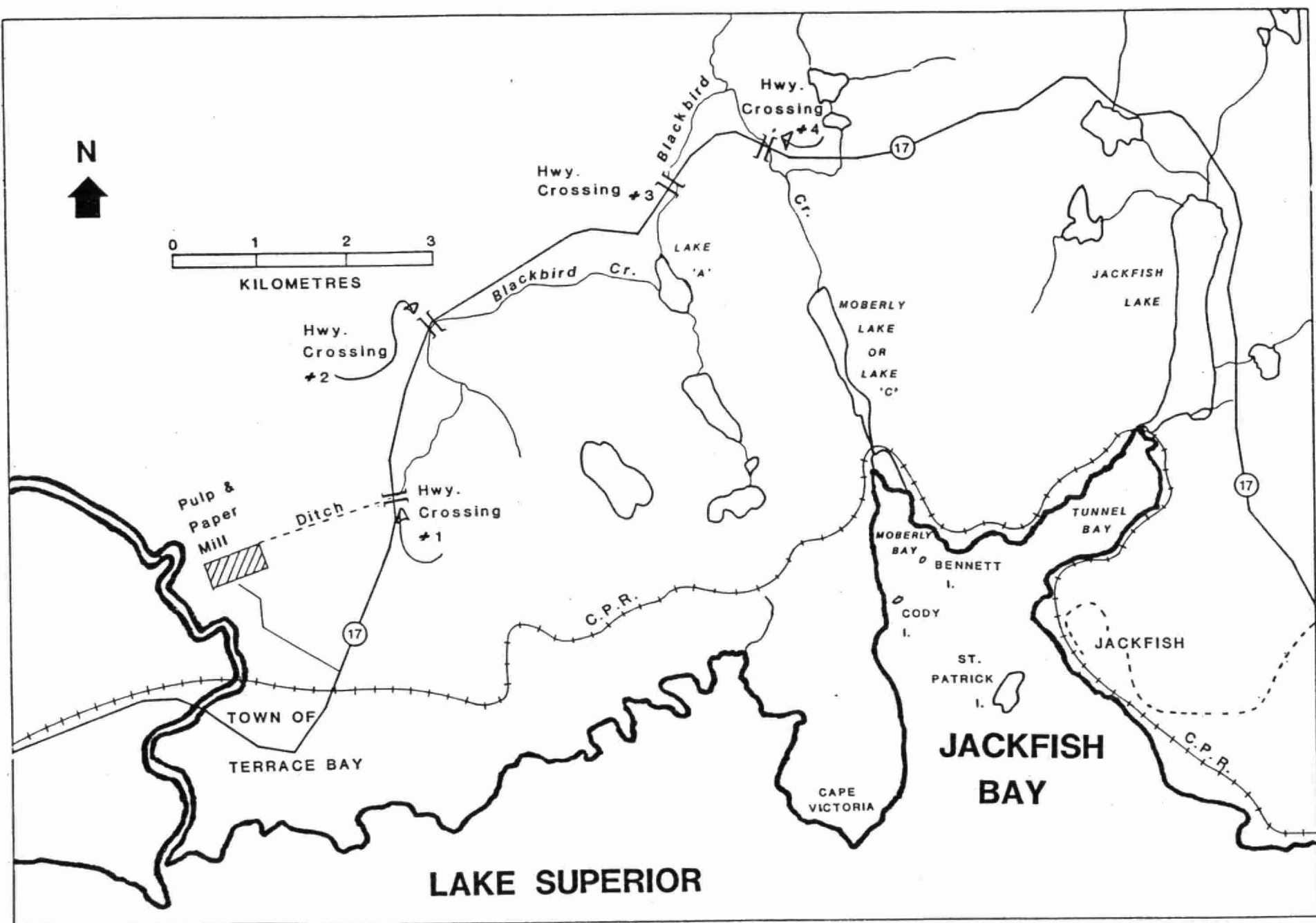
Figure 1: Map Showing the Location and Bathymetry of Jackfish Bay

At the time of the 1973 water quality survey, the manufacturing processes in the mill included wet drum debarking, a six-stage bleaching process using chlorine in the first step and sluicing of burnt bark ash into the mill effluent. Mill effluent, which contained both pulp effluent and treated sewage, was discharged into a canal adjacent to the mill. The canal emptied into the headwaters of Blackbird Creek which flowed for approximately 15 km and passed through two lakes on the way to Jackfish Bay on Lake Superior (Figure 2). The two lakes, Lake A and Lake C or Moberly Lake, acted as sedimentation basins for removal of settleable solids. Compliance in 1973 was assessed at the mouth of Blackbird Creek where it enters Jackfish Bay.

By the time of the 1981 survey several modifications had been made to the existing mill and a second one had been constructed. Modifications to the existing mill and features incorporated in the design of the second mill included a change to dry debarking, partial substitution of chlorine dioxide for chlorine in the first bleaching step, a dry ash handling system with facilities for disposal at a landfill site, a new recovery furnace and high efficiency precipitator, an incinerator for non-condensibles and a scrubber on the lime kiln. A spill control system was built and the sanitary sewage was segregated and passed through a clarifier before it was combined with the mill effluent. These measures were expected to reduce water consumption of the mill, the toxicity of the effluent, the BOD and suspended solids concentration of the effluent and TRS (total reduced sulphur) emissions from the stacks. TRS comprises a group of sulphur-containing gases (e.g. H_2S , SO_2 and methylmercaptan) which are commonly emitted from Kraft pulp mills and which are responsible for odour problems.

In addition to the changes in plant operating procedures that occurred between the 1973 and 1981 surveys, Blackbird Creek was diverted to bypass Lake A which had gradually filled with sludge. At the time of initial mill construction in 1948, Lake A occupied a

Figure 2: Map of the Blackbird Creek System



surface area of 47 acres and had a maximum depth of 20 feet (Rowley 1962, in the German and Pugh 1969). A further change between the two surveys was that beginning in 1980 the Ministry of the Environment required Kimberly-Clark to sample its effluent at the mill, as well as at Jackfish Bay to assess the effectiveness of the abatement procedures.

The average effluent flow from the mill in 1981 was 113.8×10^3 /day. The average loads of phosphorus suspended solids and BOD were 2.1, 4,770 and 30,570 kg/day, respectively. The mill was not in compliance with the BOD requirements. The suspended solids were low due to a mill shutdown following a fire in the fall of 1981 (Archer and Hawley 1982).

No use, other than waste treatment, is made of Blackbird Creek. The creek and the surrounding property are owned by Kimberly-Clark. Sportfishing and pleasure boating are carried out in Tunnel Bay, the eastern arm of Jackfish Bay, and in the open waters of Jackfish Bay.

5. METHODS

Water Samples

Water samples were collected at the second and fourth crossings of Highway 17 on Blackbird Creek (Figure 2) in April and at the fourth crossing in May to characterize the effluent and assist in the selection of parameters to measure in Jackfish Bay. Thirty-two locations were chosen in the Bay to surround and encompass the area identified in previous surveys as impaired (Ministry of the Environment 1972, Kinkead et al no date) (Figure 3).

Eighty-two parameters were selected for measurement, but not all were measured at every location. The parameters included conventional parameters such as dissolved oxygen, pH and turbidity, as well as pollutants characteristic of the pulp industry such as resin and fatty acids (Appendix 1). All samples were collected at a depth of .5 m or 1 m, which was within the depth range of maximum plume concentration. The depth range of maximum plume concentration was determined by taking vertical profiles of conductivity, temperature, pH and/or total phenolics at several locations in Jackfish Bay. Sampling was conducted daily at all locations, except station 701, over 2, 3-day periods from June 23 to 25 and from September 14 to 16.

Station 701 was located in Moberly Creek just downstream of the point of effluent discharge. It was sampled more intensively than other locations in order to establish the magnitude of temporal variability in the concentration of some of the parameters in the discharge. Sampling at station 701 for bacteria and conventional parameters was conducted four times a day, at 9:00 and 11:00 a.m. and at 1:00 and 3:00 p.m. Samples for polychlorinated biphenyls, organochlorine pesticides, phenolic compounds and resin and fatty acids were collected at the same times as the above, but were combined to form single composites prior to analysis. All laboratory analyses were performed by the Ministry's laboratories in Thunder Bay and Toronto according to the methods described in Outlines of Analytical Methods (Ministry of the Environment 1981), and in Adamek and Au (1979).

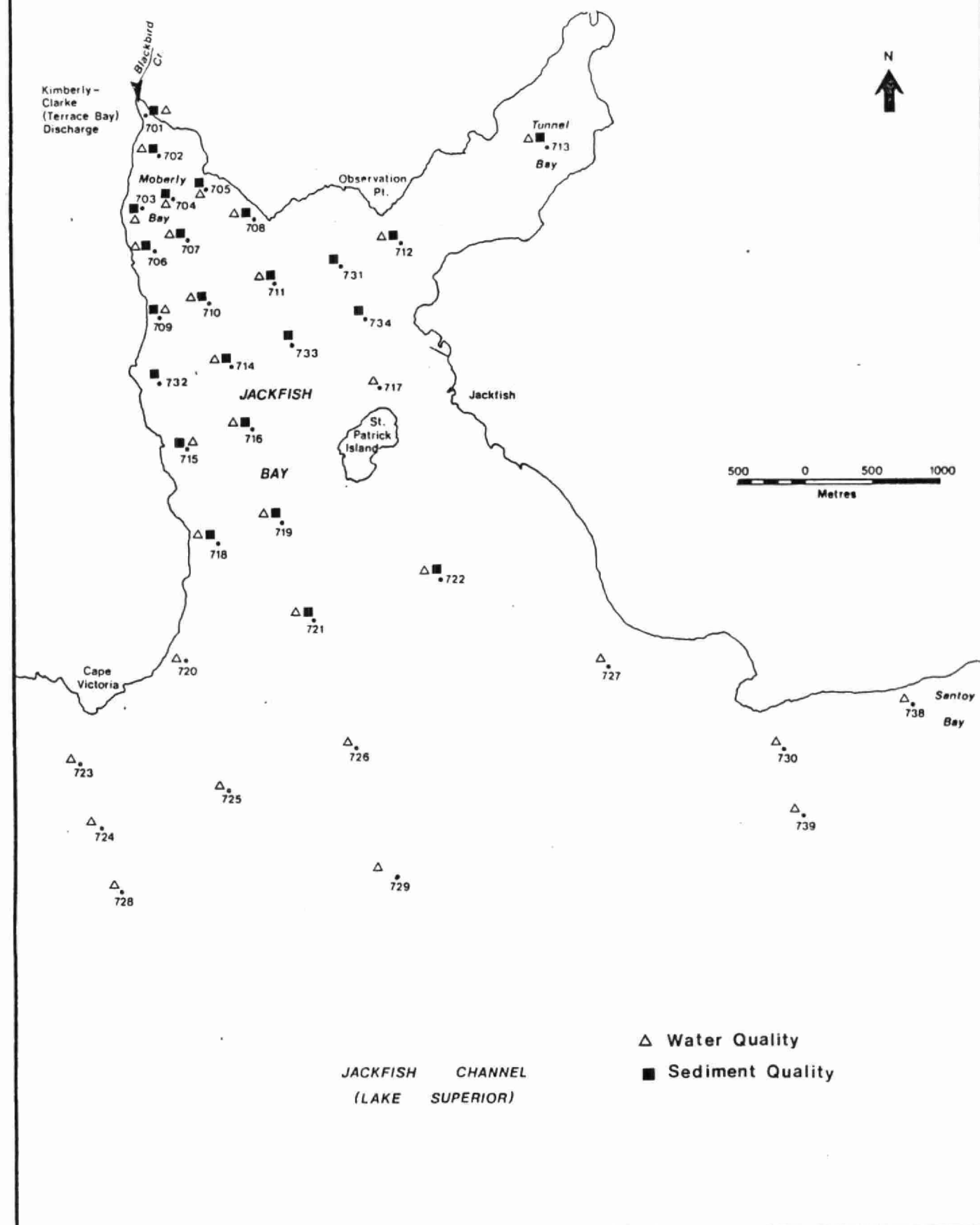


Figure 3: Sampling Locations Jackfish Bay - 1981

Sediment Samples

The grid of stations used to sample sediments was similar to that used for water quality, but less extensive (Figure 3). Three samples of the top 3 cm of sediment were collected at each location using a Shipek grab sampler and combined into a composite. The composite was analyzed for the parameters listed in Appendix 2. Particle size fractions were determined using wet sieving and hydrometer analysis. Chemical analyses were performed on bulk samples by the Ministry's laboratory in Toronto according to the methods described in Outlines of Analytical Methods (Ministry of the Environment 1981).

6. RESULTS AND DISCUSSION

Effluent Characteristics

For the purposes of this study, the samples collected at the two crossings of Highway 17 over Blackbird Creek were treated as effluent samples. The mill discharge enters Blackbird Creek at its headwaters and comprises 90% of the stream flow in the upper reaches (pers. comm., J. VanderWal, Ministry of the Environment, Northwestern Region). The concentration of parameters measured at the two crossings are presented in Table 1. Since there are no provincial objectives for the concentration of compounds in effluents, the Provincial Water Quality Objectives (PWQO) were used as a guide in interpreting these results. It should be recognized, however, that these are likely more stringent than ones that would be applied to discharges.

Of the thirteen compounds in Table 1 for which objective or interim water quality objectives have been set, eight were detected at levels which exceeded objectives. These included metals (cadmium, copper, lead and zinc), organics (phenol, pentachlorophenol, total polychlorinated byphenyls) and bacteria (fecal coliforms). All, except the bacteria, have been identified as Priority Pollutants by the Environmental Protection Agency in the United States. Their designation as priority pollutants indicates that they are recognized as potentially hazardous to aquatic life and/or human health. By far, the largest violation of the objectives was by fecal coliforms. The concentration of fecal coliforms was 50,000 times the objective of 100 counts/100 mls. This indicates that the effluent would have to be diluted by 1:50,000 (i.e. 1 part effluent to 50,000 parts receiving water), in order to meet the Provincial Water Quality Objective in the receiving water. The actual dilution for the Kimberly-Clark effluent in Jackfish Bay has been estimated to be 1:20 at about 6 km from the point of discharge (Cherwinsky and Murray 1986).

TABLE 1

Concentration of Parameters Detected in the Effluent
of the Kimberly-Clark Terrace Bay Mill as measured at two
Points along Blackbird Creek

	A P R I L		M A Y	PWQO
	#2	#4	#4	
Conventional Parameters				
DOC mg/L	320	200	-	
COD mg/L	1,070	775	-	
BOD ₅ mg/L	240	190	-	
Conductivity us/cm	2,100	1,600	-	
Total Solids mg/L	1,890	1,390	-	
Suspended Solids mg/L	160	80	-	
Dissolved Solids mg/L	1,730	1,310	-	
Colour hazen units	1,168	1,185	-	
Turbidity FTU	12	10	-	
pH	6.7	6.5	-	6.5 - 8.5
Tannins	150	50	-	
Sulphate	34.5	44.3	-	
Metals				
Arsenic mg/L	0.008	0.003	-	0.1
Cadmium mg/L	0.002	0.002	-	0.0002
Chromium mg/L	0.045	0.027	-	0.1
Copper mg/L	0.025	0.012	-	0.005
Nickel mg/L	0.01	0.004	-	0.025
Lead mg/L	0.027	0.021	-	0.010
Zinc mg/L	0.081	0.066	-	0.030
Phenolic Compounds				
Phenol ug/L	53	53	-	1.0
Vanillin ug/L	102	46	-	
Guaiacol ug/L	252	174	-	
Acetovanillon ug/L	51	38	-	
2,3,4 trichlorophenol ng/L	-	-	1,300	Total 18,000
2,4,6 trichlorophenol ng/L	-	-	5,800	
2,3,5,6 tetrachlorophenol ng/L	-	-	2,900	
pentachlorophenol ng/L	-	-	1,100	500
Organohalides				
Chloroform ug/L	69.5	81.9	-	1,200 ¹
Bacteria (counts/100 ml)				
Fecal Coliforms	5x10 ⁶	5x10 ⁶	-	100
Heterotrophs	3x10 ⁴	3x10 ⁴	-	
Sulphate Reducers	2.4x10 ⁵	1.1x10 ⁶	-	

TABLE 1 (cont'd)

	A P R I L		M A Y	PWQO
	#2	#4	#4	
PCB's and Organochlorine Pesticides				
PCB's total ng/L	-	-	80	1
Hexachlorobenzene ng/L	-	-	10	
Fatty Acids				-
Capric mg/L	ND	0.03	-	-
Palmitic mg/L	0.85	0.54	-	-
Stearic mg/L	0.99	0.82	-	-
Oleic mg/L	1.76	1.31	-	-
Linoleic mg/L	1.57	1.82	-	-
Linolenic mg/L	0.33	0.5	-	-
Arachidic mg/L	1.51	1.22	-	-
Aromatic Acids				
Salicylic mg/L	0.21	2.37	-	-
Phthalic mg/L	0.16	0.56	-	-
Resin Acids				
Pimaric mg/L	1.88	0.9	-	-
Sandaracopimaric mg/L	0.23	0.11	-	-
Levopimaric mg/L	0.11	0.08	-	-
Isopimaric mg/L	0.68	0.31	-	-
Neoabietic mg/L	3.52	1.99	-	-
Abietic mg/L	3.87	2.05	-	-
Dehydroabietic mg/L	0.57	0.37	-	-

ND not detected

- no sample

PWQO Provincial Water Quality Objective

1 Interim Provincial Water Quality Objective

mg/L milligrams per litre

ug/L micrograms per litre

FTU Formazin Turbidity Units

us/cm microsiemens/centimetre

Of the compounds for which no objectives have been set, the resin and fatty acids are of particular concern because they are the principal substances responsible for the toxicity of pulp and paper effluents to fish. A toxicity test was not performed on the Kimberly Clark effluent in April or May of 1981. However, concentrations of abietic, pimaric and isopimaric acids were up to three times reported 96-hour LC_{50} concentrations for rainbow trout (Tomlinson 1980). In addition, the concentration of guaiacol, a phenol, was up to 2 1/2 times the threshold value for taste impairment in fish (Shumway and Palensky 1973). Other compounds which are toxic and impair the flavour of fish were present in the effluent, but at concentrations below established 96-hour LC_{50} concentrations and taste impairment thresholds.

Spatially, the concentration of most parameters at the 4th highway crossing was less than at the 2nd located further away from the mill, a fact that would be anticipated if Blackbird Creek were an effective waste treatment system. It is possible that further reductions in the concentration of these parameters would occur by the time the Creek entered Jackfish Bay.

Mill Operation During the Survey

Daily average production figures for June and September and for 1981 are presented in Table 2. The mill operated continuously in June with production exceeding the annual average by less than 10%. This indicates that the spring survey was conducted under conditions which are fairly representative of 1981. September production was reduced compared to the annual average and the mill was shut down for maintenance from September 7 to 10. Start-up operations began on September 11th and the mill was fully operational by September 14th, the first day of the fall survey. Time of travel from the mill through the Blackbird Creek system to Jackfish Bay has been estimated by the Ministry of the Environment (1980, unpublished) to be 5-6 days. Assuming a five-day time of travel, effluent discharged from the mill on September 11th would not reach the mouth of Blackbird Creek until September 16th, the last day of the fall survey. Consequently, the results of the September survey cannot be considered typical of 1981.

TABLE 2

Production Figures for the Kimberly-Clark
Terrace Bay Mill
- 1981 -

	Production (admt/d) ¹	BOD (mt/d) ²	Solids (mt/d)	Flow (m ³ /d) ⁵
June	971	36.3	6.3	137,488
September	782	32.4	5.5	111,600
1981 average ³	895	35.8	6.8	123,939

1 air dried metric tons/day

2 metric tons/day

3 1981 average is based on the 10 months (January - October) during which the mill was operating. It was destroyed by fire on October 31, 1981.

4 These were based on measurements made at the mill and would underestimate the volume discharged into Jackfish Bay.

5 Cubic metres/day

Water Quality at Station 701

Water quality at all locations is likely to vary daily as a result of changes in mill effluent volume and quality, changes in the flow of Blackbird Creek and/or changes in factors which affect plume dispersion (e.g. wind direction). Due to the proximity of station 701 to the point of effluent discharge, the greatest source of daily variation in the water quality at this location during each sampling period is probably the changes in effluent quality and volume. Consequently, an analysis of variance of the data from this location should provide an indication of the uniformity of mill output during each sampling period. The analysis was performed on the data from each period separately after transformation to a logarithmic scale to meet with the homogeneity of variance assumption of ANOVA (Snedecor and Cochran 1967). Of the parameters with complete data in June (Table 3), the differences in the daily mean concentrations of suspended solids and conductivity were statistically significant ($p < .05$), while of those measured in September only differences in the mean concentrations of phenols were significant. The lack of significance in the daily variation of the remaining parameters suggests that their daily mean concentrations were relatively constant during each survey and that factors other than effluent quality and quantity are primarily responsible for the day-to-day variation in water quality at other locations.

The general lack of significant trends in the parameters measured in September suggests that effluent discharged from the mill following start-up had not reached the mouth of Blackbird Creek by the end of the survey. This is not entirely unexpected as the minimum estimate of time of travel was 5-6 days. At the earliest, effluent would reach the mouth of Blackbird Creek on September 16th, the last day of the survey.

TABLE 3

Geometric Mean Concentrations and Range in Concentrations
of Conventional Parameters at Station 701

		J U N E			S E P T E M B E R		
		23	24	25	14	15	16
BOD	\bar{x}	66.4	68.1	78.8	45.3	42.3	45.7
(mg/L)	r	60-75	55-80	72-86	41-50	20-64	45-47
COD	\bar{x}	457	337	441	305	230	250
(mg/L)	r	390-510	250-410	340-798	300-310	100-310	200-300
Turbidity	\bar{x}	3.13	2.99	3.10	8.46	8.33	7.01
(FTU)	r	2.9-3.4	2.7-3.4	3.0-3.2	7.1-9.3	5.4-9.9	6.5-7.6
Colour	\bar{x}	890	838	1014	818	618	779
(hazen units)	r	843-931	640-991	915-1104	748-855	352-755	767-789
Suspended Solids	\bar{x}	62.1	20	26.3	22	17	20
(mg/L)	r	40-120	20-20	20-40	20-30	10-20	20-20
Conductivity	\bar{x}	1183	885	1101	948	778	915
(us/cm)	r	1170-1190	740-980	1060-1125	860-1000	520-920	900-940
Total Solids	\bar{x}	-	-	-	775	633	727
(mg/L)	r	-	-	-	740-810	380-750	720-740
Dissolved Solids	\bar{x}	-	71	84	752	616	707
(mg/L)	r	-	58-81	71-96	720-790	370-730	700-720
Sulphate	\bar{x}	-	-	-	83	88	107
(mg/L)	r	-	-	-	71-91	48.5-110	105-110
DOC	\bar{x}	-	-	-	52.6	37.0	43.1
(mg/L)	r	-	-	-	46.0-57.5	17.5-48.5	41.0-46.0
Phenols	\bar{x}	335	-	353	55	170	233
(mg/L)	r	325-340	-	340-380	51-58	165-174	216-244

- no data
 \bar{x} geometric mean
r range
mg/L milligrams/Litre
us/cm microsiemens/centimetre
FTU Formazin Turbidity Units

Water Quality in Jackfish Bay

a) Conventional Water Quality Parameters

A summary of the concentrations of conventional water quality parameters measured in Jackfish Bay is presented in Table 4. A Mann Whitney U Test was used to compare the distributions of each parameter in June with that in September. Statistically significant differences were detected ($p < .05$) for all parameters tested, except BOD. The medians of most parameters in September were lower than in June, indicating that a rapid improvement in most conventional water quality parameters can be expected after an improvement in effluent quality.

The conventional parameters measured in June 1981 were compared with those measured in late August and early September of 1970 using a Mann Whitney U Test. 1970 was selected as a basis of comparison rather than 1973 because the sampling locations and sampling design were more similar to those in 1981. Prior to the test, the mean of the three sampling days at each location in 1981 was calculated to give data comparable to that available in the 1970 report (Ministry of the Environment 1972). Only data from locations which were similar in 1970 and 1981 were used in the comparison. The 1981 locations included stations 701-711 and 715-719. Statistically significant differences were detected for COD, colour, pH, sulphate and phenols. The median value of these parameters were higher in 1981 as compared to 1970 (Table 5). The differences in BOD between 1970 and 1981 were not statistically significant. A deterioration in water quality between 1973 and 1981 is suggested by the deterioration between 1970 and 1981 described above and by the improvement between 1970 and 1973 suggested by Kinkead et al (no date).

b) Metals

Sampling for most metals was restricted to station 701 where the Provincial Water Quality Objectives for mercury, cadmium, copper, nickel and zinc were exceeded during the June and/or September survey periods (Tables 6 and 7). The maximum concentration of copper was 400 times the objective and that of zinc, 3 times the objective.

TABLE 4

Summary of the Water Quality at Stations 701-726
in Jackfish Bay, 1981

	JUNE	SEPTEMBER
DOC (mg/L) median range	4.1 1.2-88.5	1.6 0.5-57.5
COD (mg/L) median range	20 <10-510	- -
BOD (mg/L) median range	1.8 0.1-75	0.6 0.1-50
COND (us/cm) median range	155 100-1190	106 93-790
Suspended solids (mg/L) median range	1 1-120	1 1-30
Colour (hazen units) median range	29 1-931	10 4-855
Turbidity (FTU) median range	0.6 0.15-3.4	0.30 0.15-9.5
Temperature (°C) median range	10 6-14	13.5 12-14.5

- Insufficient Data

TABLE 5

Summary of the Water Quality at Stations
Used in 1970 and 1981

	1970	1981
COD (mg/L)		
median	<10	34.2
range	<10-845	6.7-421.6
BOD (mg/L)		
median	1.6	3.9
range	1.2-240.6	0.1-71.9
Sulphate (mg/L)		
median	1.3	6.4
range	1-11	3.6-20.0
Colour (Hazen Units)		
median	10.5	72.2
range	2-2500	10.7-921.3
pH		
median	7.2	7.6
range	6.7-7.4	7.5-8.1
Reactive Phenolics (ug/L)		
median	10	33.5
range	<1-670	3-344.2

TABLE 6

Concentrations (mg/L) of Metals Detected
at Station 701 in Jackfish Bay
- 1981 -

		<u>Cadmium</u>	<u>Chromium</u>	<u>Copper</u>	<u>Nickel</u>	<u>Lead</u>	<u>Zinc</u>
June 23	9:00 am	-	-	-	-	-	-
	11:00 am	0.003	0.015	0.010	0.005	0.042	0.050
	1:00 pm	0.002	0.020	0.009	0.007	0.039	0.060
	3:00 pm	0.002	0.011	0.010	0.004	0.048	0.050
June 24	9:00 am	0.002	0.009	0.040	-	-	0.050
	11:00 am	0.002	0.008	0.008	-	-	0.030
	1:00 pm	0.003	0.009	0.006	-	-	0.040
	3:00 pm	0.003	0.011	0.020	-	-	0.040
June 25	9:00 am	0.003	0.012	-	-	-	0.050
	11:00 am	0.003	0.011	-	-	-	0.050
	1:00 pm	0.002	0.007	-	-	-	0.050
	3:00 pm	0.002	0.009	-	-	-	0.040
Sept. 14	9:00 am	0.007	0.023	1.000	0.028	0.004	0.046
	11:00 am	0.002	0.017	1.200	0.012	0.002	0.042
	1:00 pm	0.002	0.013	2.000	0.017	0.001	0.090
	3:00 pm	0.002	0.011	0.008	0.015	0.001	0.038
Sept. 15	9:00 am	0.002	0.011	0.072	0.014	0.001	0.040
	11:00 am	0.002	0.013	0.047	0.014	0.001	0.031
	1:00 pm	0.002	0.011	0.008	0.017	0.001	0.028
	3:00 pm	0.002	0.011	0.008	0.015	0.001	0.029
Sept. 16	9:00 am	-	0.015	0.003	0.016	0.001	-
	11:00 am	-	0.009	-	0.016	0.001	-
	1:00 pm	-	-	-	-	-	-
	3:00 pm	-	-	-	-	-	-
Provincial Water Quality Objective		0.0002	0.100	0.005	0.025	0.005	0.300

- Not Sampled

TABLE 7

Concentrations (ug/L) of Mercury in Jackfish Bay
- 1981 -

<u>Station</u>		<u>June 23</u>	<u>June 24</u>	<u>June 25</u>	<u>Sept.14</u>	<u>Sept.15</u>	<u>Sept.16</u>
701	9:00 am		0.14	-	<0.05	<0.05	0.08
	11:00 am	3.3	0.08	-	<0.05	<0.05	<0.05
	1:00 pm	1.1	<0.05	-	0.07	<0.05	<0.05
	3:00 pm	3.0	<0.05	-	0.05	<0.05	<0.05
702		3.0	0.05	0.11	<0.05	<0.05	<0.05
704		1.7	-	0.15	0.39	<0.05	<0.05
707		1.2	<0.05	0.16	<0.05	<0.05	<0.05
709		1.1	<0.05	<0.05	<0.05	<0.05	<0.05
710		1.2	<0.05	<0.05	<0.05	<0.05	<0.05
711		1.6	<0.05	<0.05	-	<0.05	-
712		-	-	-	-	<0.05	<0.05
713		0.73	<0.05	<0.05	-	-	-
714		0.92	0.05	<0.05	<0.05	<0.05	<0.05
719		1.7	-	0.10	<0.05	<0.05	<0.05

- Not sampled.

Provincial Water Quality Objective = 0.2 ug/L

The detection of cadmium, copper and zinc in Blackbird Creek in April at concentrations which exceeded the Provincial Water Quality Objective suggest that the mill is a source of the contamination. However, the mill is unlikely the only source as the highest levels of copper and zinc were observed on September 14, before effluent would be expected to reach the mouth of Blackbird Creek after the September start-up operations. These results suggest a need for a more extensive survey of metal concentrations in Jackfish Bay to delineate the area impacted and for an investigation of potential sources.

Unlike other metals, mercury was sampled at station 701 and a number of locations in Jackfish Bay (Table 7). On June 23 mercury concentrations exceeded the Provincial Water Quality Objective of 0.2 ug/L at all locations sampled. The concentrations were highest at the mouth of Blackbird Creek and generally decreased with distance from the Creek. Although mercury was not detected in Blackbird Creek in April, the distinct spatial pattern apparent in the Bay in June suggests that the mill was the source. The only other violation of the mercury objective occurred on September 14 at station 704.

c) Bacteria

Violations of the Provincial Water Quality Objective for the protection of recreational water uses for fecal coliforms (geometric mean of 100 counts/100 ml) occurred over an extensive area of Jackfish Bay in June (Figure 4). Sampling for fecal coliforms was not conducted in September. Although the sampling frequency in June was less than the recommended 10 samples per month, the high numbers encountered throughout much of the area suggests that a potential health risk may exist. However, the analytical test used to detect fecal coliforms is sensitive to the presence of Klebsiella pneumoniae, a coliform which is common in pulp and paper mill effluents and which is not normally found in large numbers in human wastes (Ministry of the Environment 1983). The health risks associated with K. pneumoniae are the subject of much debate. Some argue that K. pneumoniae is ubiquitous and of little health significance, while others note that this coliform is responsible for 60-70% of the deaths due to bacterial pneumonia in the United States (Leggatt 1983).

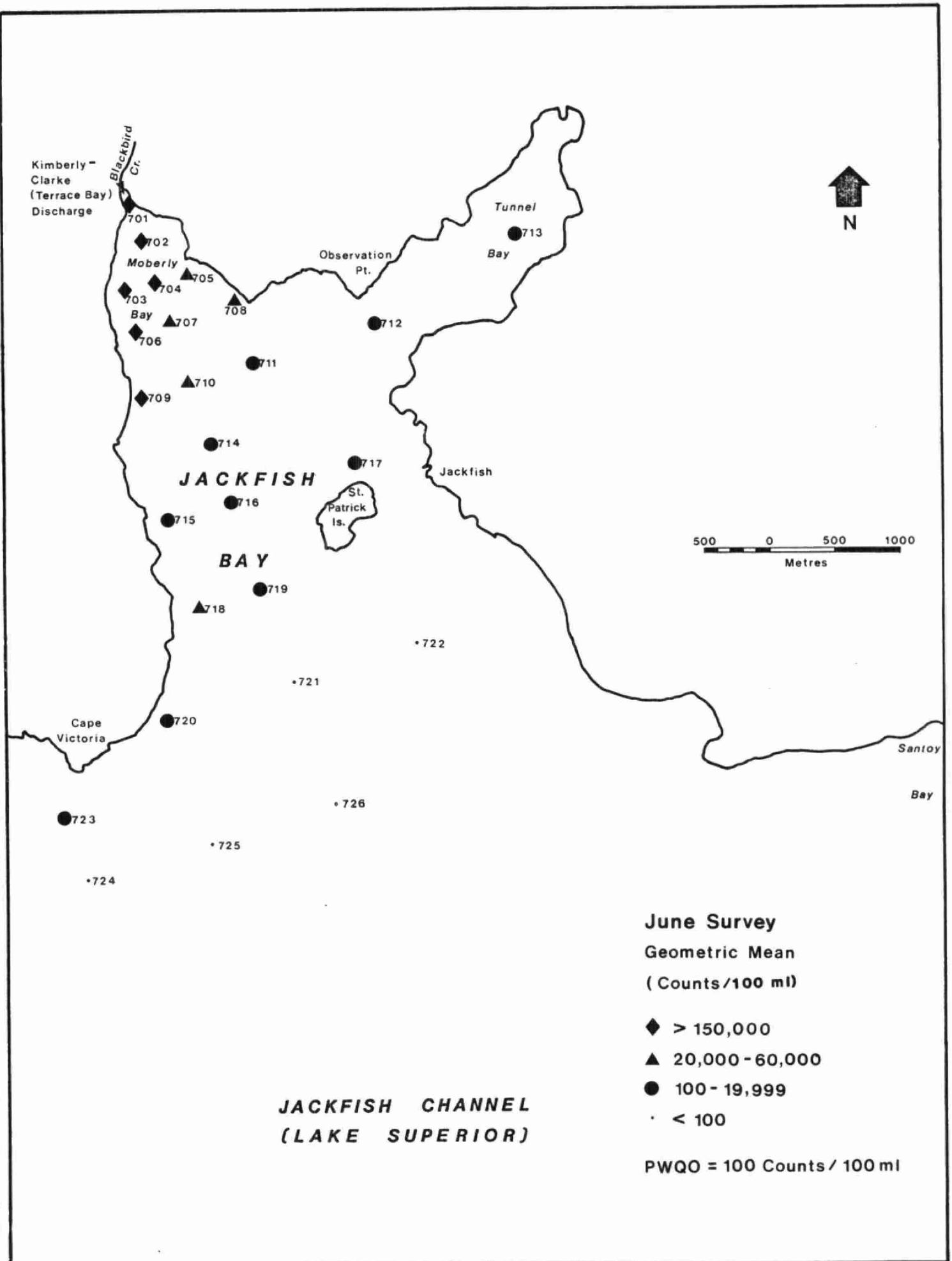


Figure 4: Locations Where the Provincial Water Quality Objective for Fecal Coliforms was Exceeded During the June Survey

The distribution of heterophilic bacteria in June, 1981, exhibits a pattern similar to that of the fecal coliforms with the highest numbers being recorded at the mouth of Blackbird Creek and with a rapid decline in numbers occurring over a distance of about 0.8 - 1.5 km from the mouth of the Creek (Figure 5). No Provincial Water Quality Objective exists for heterotrophs. The high numbers near the mouth of the Creek are indicative of high concentrations of organic pollutants.

d) Organic Compounds

The Provincial Water Quality Objective to protect against tainting of edible fish flesh for reactive phenolics (1 ug/L) was exceeded at sampling stations located up to 4 km from the mouth of Blackbird Creek in June and up to 2.5 km, in September. The maximum values measured during both surveys were at station 701 where levels reached 380 ug/L in June and 244 ug/L in September. The most rapid spatial decline in reactive phenol concentrations occurred between stations 701 and 702. The highest levels at station 702 were 160 ug/L and 8 ug/L in June and September, respectively. Concentrations at the remaining locations were less than 80 ug/L in June and 6 ug/L in September.

The phenol concentrations measured by the reactive phenolics test are not directly interpretable in terms of toxicity or organoleptic potential. The analytical technique varies in sensitivity to the presence of phenol and various substituted phenolics. Consequently, two samples with the same concentration of reactive phenols may actually contain quite different compounds or quite different concentrations of the same compounds. Since individual phenolics can also vary greatly in toxicity and ability to impart taste and odour to water, the samples can also potentially differ in toxicity and organoleptic properties (de Barros 1984).

In an attempt to increase the interpretability of the results, additional analyses for phenol, and a number of chlorophenols and other substituted phenols were performed on water samples from a few locations in the bay. The concentrations of the parameters detected

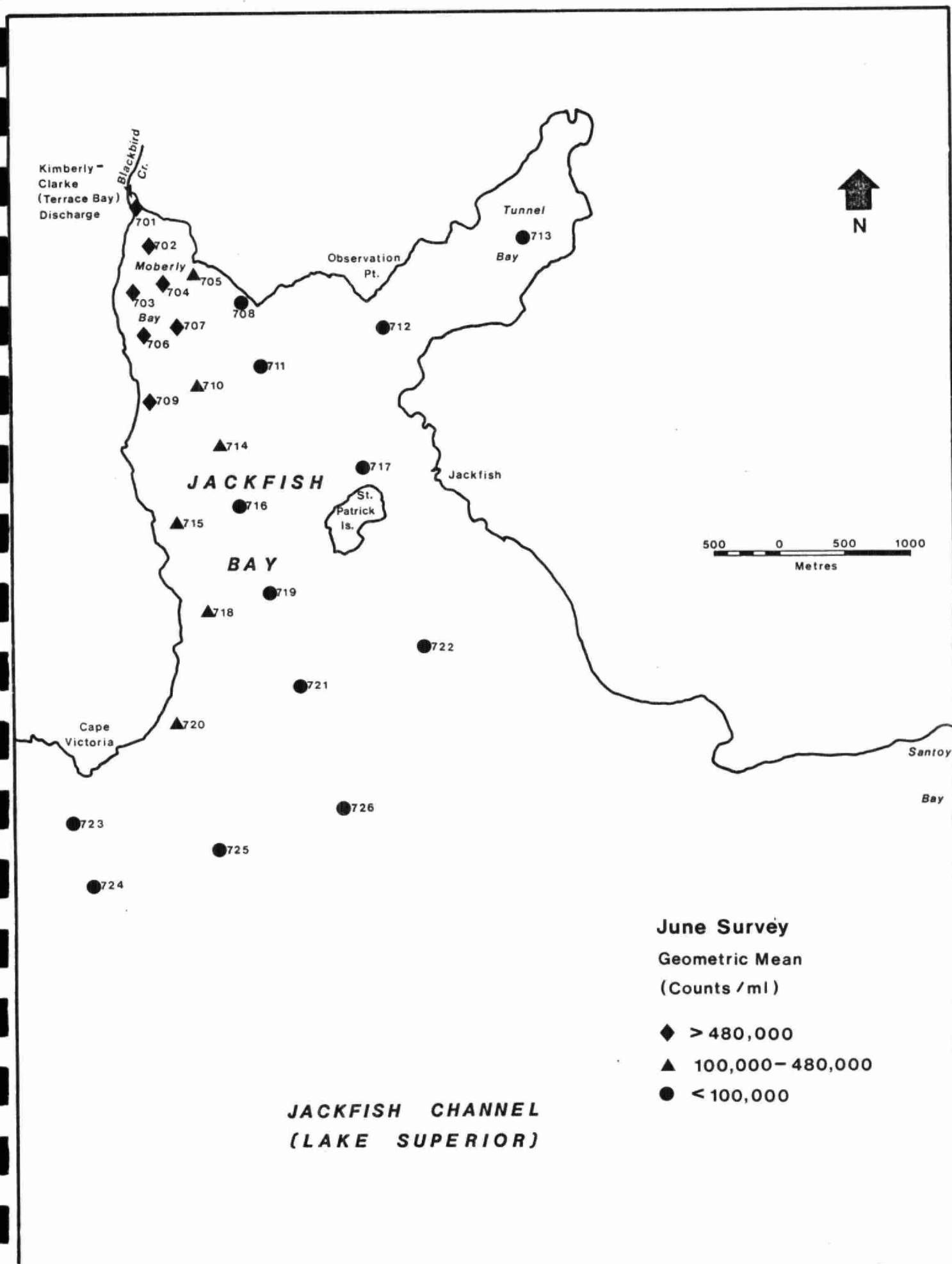


Figure 5: Distribution of Heterotrophic Bacteria in Jackfish Bay, June 1981

are listed in Table 8. Provincial Water Quality Objectives exist for two of the compounds for which analyses were done, namely trichlorophenols (18 ug/L) and pentachlorophenol (0.5 ug/L). The later objective was exceeded at station 701 in Blackbird Creek on June 23. Of the remaining phenolics, guaiacol was detected above levels which taint fish flesh (100 ug/L, Shumway and Palensky 1973) at stations 701 and 702 in June and at station 701 in September, and above the odour threshold of 21 ug/L (Verschueren 1983, in de Barros 1984) at stations 701, 702 and 704 in June and at station 701 in September. All the phenols detected in Jackfish Bay in June and September, except homovanillic acid, had been found in the Blackbird Creek samples in April, implicating the mill as the source.

Other organic compounds for which analyses were conducted were aromatic, and resin and fatty acids (Table 9). The resin and fatty acids are of particular concern since they are the principal substances responsible for the toxicity of pulp and paper mill effluents to fish. Abietic acid concentrations exceeded the 96-hour LC_{50} concentration for trout (1.1 mg/L, Tomlinson 1980) in June and September at station 701, as did the concentration of isopimaric acid in June (96-hour LC_{50} = 0.7 mg/L, Tomlinson 1980). The wide range of compounds detected at station 701 in June, and the persistence of some toxic compounds in September after the mill shutdown, suggest a need for more extensive sampling for these compounds to determine the size of the impacted area.

Sediment Quality

a) Particle Size, Metal Concentrations and Physical Characteristics

Results of the analyses of the sediment samples for particle size distribution, metal concentrations and other chemical and physical characteristics are presented in Tables 10 to 12. Currently, there are no provincial guidelines for sediment quality. However, the Spoils Disposal Guidelines indicate that the sediments of Jackfish Bay were highly contaminated in 1981. Levels of chromium, iron, copper, oil and

TABLE 8

Concentrations (ug/L) of Phenolic Compounds Detected in Jackfish Bay - 1981

			2,3,4 TCP	2,4,6 TCP ²	2,3,5,6 TTCP	PCP ¹	Phenol	Homovanillic Acid	Vanillin	Guaiacol	Aceto-vanillin
701	June	23	1.30	3.30	0.60	0.54	ND	-	-	-	-
		24	ND	1.85	0.25	0.25	ND	263	100	235	-
		25	0.23	0.70	0.13	-	ND	212	106	265	-
702	June	23	ND	2.00	0.30	0.25	ND	158	55	119	-
		24	ND	1.60	0.25	ND	ND	79	36	77	-
704	June	23	0.08	0.52	0.08	0.11	ND	40	19	48	-
		24	0.08	0.45	0.08	0.19	ND	ND	8	24	-
705	June	23	ND	0.24	ND	0.06	-	-	-	-	-
		24	ND	ND	ND	ND	-	-	-	-	-
706	June	24	ND	0.45	0.07	0.05	-	-	-	-	-
707	June	23	ND	0.43	0.06	0.07	ND	19	8	18	-
710	June	23	ND	0.20	ND	ND	-	-	-	-	-
713	June	23	-	-	-	-	ND	ND	ND	ND	-
701	Sept.	14	ND	ND	ND	0.40	21.1	ND	ND	ND	5.2
		15	ND	ND	ND	0.15	150.0	ND	18.4	139.2	84.0
		16	ND	ND	ND	ND	42.2	ND	12.8	149.4	62.2
702	Sept.	14	ND	ND	ND	ND	ND	ND	ND	ND	ND
704	Sept.	14	ND	ND	ND	ND	ND	ND	ND	ND	ND
707	Sept.	14	ND	ND	ND	ND	ND	ND	ND	ND	ND
709	Sept.	14	ND	ND	ND	ND	ND	ND	ND	ND	ND
710	Sept.	14	ND	ND	ND	ND	ND	ND	ND	ND	ND
712	Sept.	14	ND	ND	ND	ND	ND	ND	ND	ND	ND
714	Sept.	14	ND	ND	ND	ND	ND	ND	ND	ND	ND

TTCP - tetrachlorophenol

TCP - trichlorophenol

PCP - pentachlorophenol

ND = Not Detected

- = Not Sampled

¹Provincial Water Quality Objective for PCP = 0.5 ug/L²Provincial Water Quality Objective for total TCP = 18 ug/L

TABLE 9

Concentrations (mg/L) of Aromatic, Resin and Fatty Acids
in Jackfish Bay, 1981

			<u>Fatty Acids</u>					<u>Aromatic Acids</u>		
			<u>Lauric</u>	<u>Myristic</u>	<u>Palmitic</u>	<u>Stearic</u>	<u>Oleic</u>	<u>Arachidic</u>	<u>Benzoic</u>	<u>Phthalic</u>
701	June 24		0.023	ND	0.08	0.036	0.140	0.105	0.064	0.034
	June 25		1.079	ND	0.079	0.041	0.131	0.205	0.098	0.0411
701	Sept. 14		ND	ND	0.02	ND	ND	ND	ND	ND
	Sept. 15		ND	0.05	0.04	ND	ND	ND	ND	ND
	Sept. 16		ND	ND	0.003	ND	ND	ND	ND	ND
702	Sept. 14		ND	ND	ND	ND	ND	ND	ND	ND
704	Sept. 14		ND	ND	ND	ND	ND	ND	ND	ND
709	Sept. 14		ND	ND	ND	ND	ND	ND	ND	ND
710	Sept. 14		ND	ND	ND	ND	ND	ND	ND	ND
712	Sept. 14		ND	ND	ND	ND	ND	ND	ND	ND
714	Sept. 14		ND	ND	ND	ND	ND	ND	ND	ND

Resin Acids

			<u>Sandaraco-</u>		<u>Levopimaric</u>	<u>Isopimaric</u>	<u>Neoabietic</u>	<u>Abietic</u>
			<u>Pimaric</u>	<u>pimaric</u>				
701	June 24		0.324	0.32	ND	0.54	0.5	1.36
	June 25		0.072	0.74	ND	1.21	1.2	2.27
701	Sept. 14		0.43	ND	0.06	0.15	ND	2.87
	Sept. 15		0.61	ND	0.49	0.38	0.09	2.62
	Sept. 16		0.48	ND	0.01	0.24	0.01	1.80
702	Sept. 14		ND	ND	0.43	0.04	ND	0.36
704	Sept. 14		ND	ND	ND	ND	ND	ND
709	Sept. 14		ND	ND	ND	ND	ND	ND
710	Sept. 14		ND	ND	ND	ND	ND	ND
712	Sept. 14		ND	ND	ND	ND	ND	ND
714	Sept. 14		ND	ND	ND	ND	ND	ND

ND - not detected.

TABLE 10

Concentrations (ug/g = ppm) of Heavy Metals in Jackfish Bay Sediments

Station Number	Hg	Cu	Ni	Zn	Cd	Co	Cr	Pb	Fe	Mn	Al
701	0.01	6	5.5	35	0.3	4.7	16	3	8,600	110	4,200
702	0.17	31*	19	140*	0.83	5.3	43*	8.7	9,400	150	6,200
703	0.55*	49*	23	150*	1.3*	8.2	66*	17	21,000*	300	12,000
704	0.58*	47*	23	140*	1.2*	8.3	6.3	18	22,000*	310	13,000
705	0.01	4.5	5	21	0.3	3.5	12	3	9,500	86	3,600
706	0.01	4.8	6	22	0.3	3.0	13	3	9,300	88	3,500
707	0.07	16	13	62	0.35	6.0	36*	5	16,000*	200	7,600
708	0.01	8	8.5	32	0.3	4.5	20	3	13,000*	210	5,500
709	0.01	6.4	12	51	0.3	5.0	19	4.8	15,000*	180	6,400
710	0.14	32*	19	88	0.65	8.2	45*	15	20,000*	320	9,400
711	0.01	9.3	12	31	0.3	5.7	26*	4.5	14,000*	280	4,900
731	0.08	34*	22	74	0.5	9.7	48*	21	23,000*	770	9,800
712	0.10	39*	24	86	0.68	9.8	48*	24	26,000*	1,300	12,000
713	0.11	41*	20	83	0.65	9.1	40*	27	20,000*	630	11,000
732	0.01	9.2	13	35	0.3	5.9	26*	4	14,000*	250	6,400
714	0.15	33*	21	77	0.7	8.6	41*	17	19,000*	420	10,000
733	0.01	10	13	31	0.23	5.9	55*	3.3	29,000*	280	6,000
734	0.06	29*	19	59	0.6	8.4	43*	14	19,000*	330	6,000
715	0.01	9	14	32	0.3	5.0	26*	3	15,000*	250	6,100
716	0.27	49*	24	100*	1.1*	8.8	50*	24	21,000*	460	13,000
718	0.19	44*	22	93	0.98	7.6	48*	26	21,000*	470	12,000
719	0.01	7	12	22	0.2	3.4	21	3	10,000*	230	4,300
721	0.01	21	22	46	0.2	8.9	46*	4.1	23,000*	490	12,000
722	0.01	16	17	42	0.2	7.2	37*	5.2	18,000*	320	7,500
MOE Spoils Disposal Guidelines	0.3	25	25	100	1.0	-	25	50	10,000	-	-

* - indicates level at or above MOE guidelines for open water disposal of dredged spoils.

TABLE 11

Chemical and Physical Characterization of Jackfish Bay Sediments

Station Number	pH	COD	TKN	TP	Oil & Grease	Volatile Solids (% loss on ignition)	TC	TS	Sulphides	Reducible Sulphur
701	6.1	18,000	200	500	550	0.9	2,900	2,700	95	35
702	6.1	890,000*	7,700*	1,100*	34,600*	46*	330,000	8,100	35	46
703	6.3	340,000*	4,300*	1,000*	-	18*	100,000	5,600	-	-
704	6.3	320,000*	4,300*	1,100*	11,400*	5.4	98,000	6,600	750	100
705	5.8	14,000	300	400	-	0.9	3,200	360	0.1	0.1
706	6.6	21,000	300	500	-	0.8	2,100	400	-	-
707	6.8	76,000*	900	900	4,050*	4.1	27,000	1,900	484	123
708	7.1	18,000	800	400	-	1.3	6,700	400	5.1	21
709	6.8	23,000	600	600	-	1.0	4,900	600	-	-
710	6.2	120,000*	2,000*	1,000*	2,500*	6.6*	44,000	1,900	29	153
711	7.1	13,000	500	1,100*	430	1.0	4,600	270	-	-
731	6.7	64,000*	1,200	1,000	-	3.4	27,000	650	-	-
712	6.8	68,000*	1,500	1,300*	-	4.4	26,000	790	-	-
713	6.5	87,000*	1,700	1,200*	-	5.4	29,000	820	-	-
732	7.0	18,000	300	600	-	0.9	1,800	360	-	-
714	6.4	97,000*	1,400	1,000*	2,100*	5.7	38,000	1,700	15	98
733	7.3	13,000	300	1,700*	-	0.8	4,600	270	-	-
734	6.5	52,000*	900	900	-	3.2	24,000	990	-	-
715	6.8	11,000	300	600	-	0.7	2,300	340	0.1	0.1
716	6.4	160,000*	2,300*	1,000*	6,150*	8.5*	49,000	2,500	0.1	3.3
718	6.3	120,000	1,700	1,000*	5,200*	6.5*	36,000	940	-	-
719	7.2	7,400	200	800	900	0.6	1,900	310	-	-
721	7.5	31,000	300	700	4,500*	1.6	37,000	160	-	-
722	7.0	19,000	380	1,000*	530	1.3	10,000	470	-	-
MOE Spoils Disposals Guidelines										
-	-	50,000	2,000	1,000	1,500	6	-	-	-	-

All concentrations ug/g = ppm except where noted.

* - indicates level at or above MOE guidelines for open water disposal of dredged spoils.

- - not available.

TABLE 12

PARTICLE SIZE COMPOSITION (BY %) OF BOTTOM SEDIMENTS* COLLECTED IN JACKFISH BAY

Wentworth Size Class	Gravel	Very Coarse Sand	Coarse Sand	Medium Sand	Fine Sand	Very Fine Sand	Silt	Clay
Sieve No.	10	18	35	60	120	230	By Difference	2-Hour Hydrometer Method
Particle Size in mm.	4.75 2.0	2.0 1.0	1.0 0.5	0.5 0.25	0.25 0.125	0.125 0.0625	0.0625 0.005	0.005
Station								
701	18	24	51	4	1	1	1	0
703	0	1	1	1	5	17	64	11
704	0	1	1	2	10	23	54	9
705	7	19	38	16	13	4	3	0
706	14	13	48	21	4	0	0	0
707	0	1	1	1	13	30	52	2
708	23	15	27	20	6	4	5	0
709	38	37	8	5	0.5	1.5	10	0
710	0	0	1	1	6	26	61	5
711	0	0.5	0.5	1	10	48	40	0
731	0	0	0	1	5	32	55	7
712	0	0	0.5	0.5	4	27	61	7
713	0	1	2	1	6	15	66	9
732	30	11	14	21	12	4	6	2
714	0	0.5	0.5	1	6	26	60	6
733	8	3	1	1	21	36	23	7
734	0	0	0.5	0.5	17	24	50	8
715	58	11	8	6	8	6	3	0
716	0	0	0.5	0.5	1	12	78	8
718	0	0	0	0.5	0.5	19	71	9
719	1	1	8	6	24	32	25	3
721	0	0.5	0.5	4	7	10	50	28
722	1	1	2	4	17	31	39	5

* = Composite top 3 cm of 3-grab Shipeks.

grease, chemical oxygen demand (COD) and total phosphorus (TP) exceeded the disposal guidelines throughout most of the sampling area, while concentrations of total Kjeldahl nitrogen (TKN), zinc, cadmium and mercury were higher than the dredging guidelines in a localized area near the mouth of Blackbird Creek (Figures 6 and 7). Elevated levels of metals and other parameters in the sediments are of concern for several reasons, including the potential for uptake of hazardous substances by benthic organisms and subsequent bioaccumulation in the food chain. Bioaccumulation has been shown to be important in the fate of cadmium, chromium, copper, mercury and zinc in the aquatic environment (Callahan et al 1979). In addition, there is a potential for release of the contaminants from the sediments following transformation processes. Such releases could contribute to future water quality impairment.

The spatial patterns in sediment type, metal concentrations and physical and chemical characteristics were examined using principal components analysis. Principal components analysis is a multivariate summarization technique which incorporates all the variables into the analysis at the same time. In this instance, the use of principal components analysis will allow parameters with similar spatial patterns to be identified and their spatial pattern to be represented by a new variable or component. More than one component will be required if more than one pattern exists in the original data. The computational details of the technique are described in Tatsuoaka (1971). The analysis was performed using the twenty-six sediment parameters for which data were complete. A correlation matrix was calculated and used as input to the analysis after transformation of the parameters (except pH) to a logarithmic scale.

The first component accounted for 65% of the variance present in the original data. The efficiency of the summarization is illustrated by the fact that each of the original parameters accounted for only 3.8% of the total variance in the data set. All of the original parameters, except chromium, pH, total sulphur, fine sand and very fine sand, were highly correlated with this component (Table 13). This means that they exhibited similar spatial patterns, although in instances where the correlations are of opposite signs, for example,

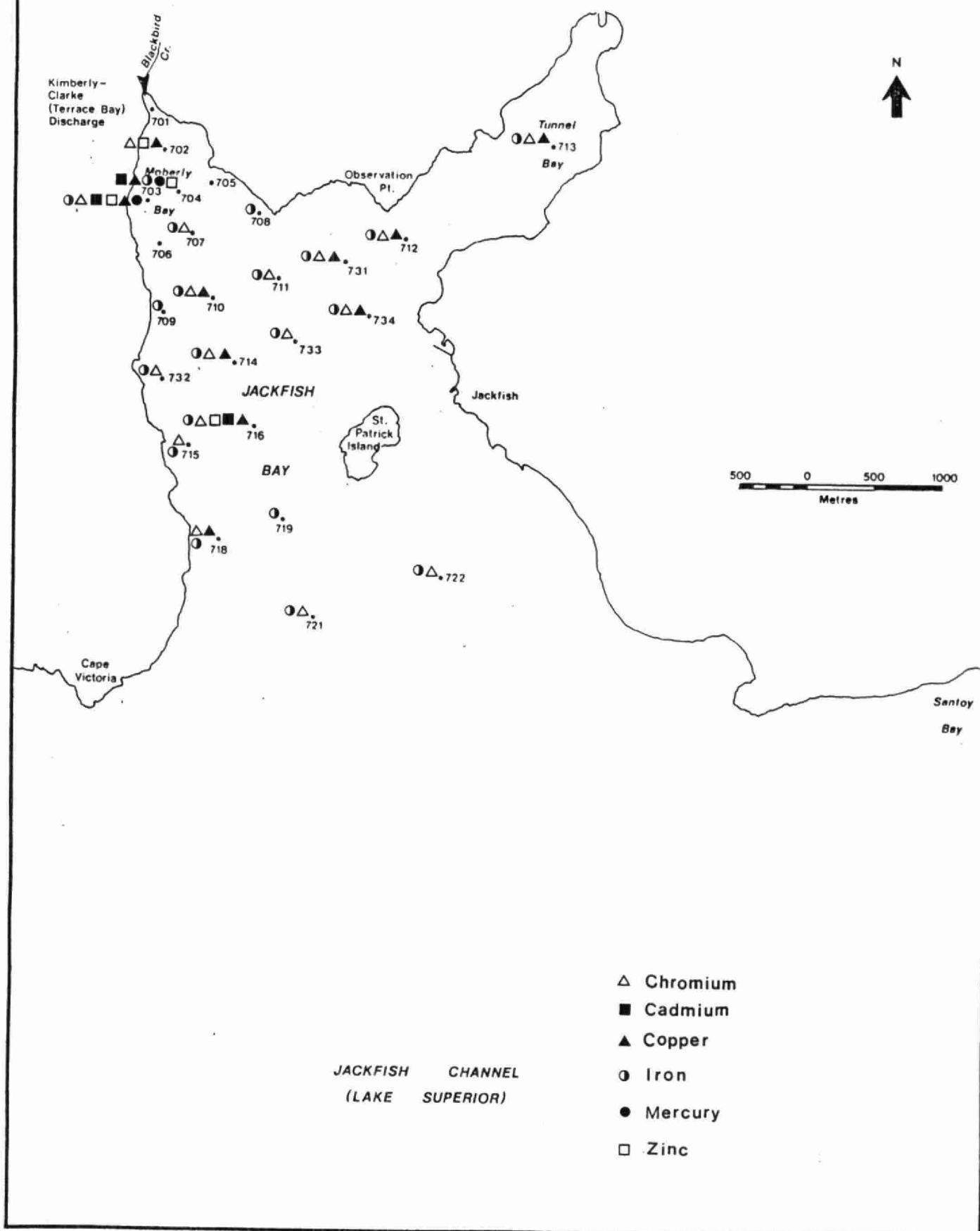


Figure 6: Locations Where Metal Concentrations in the Sediments Exceeded Disposal Guidelines

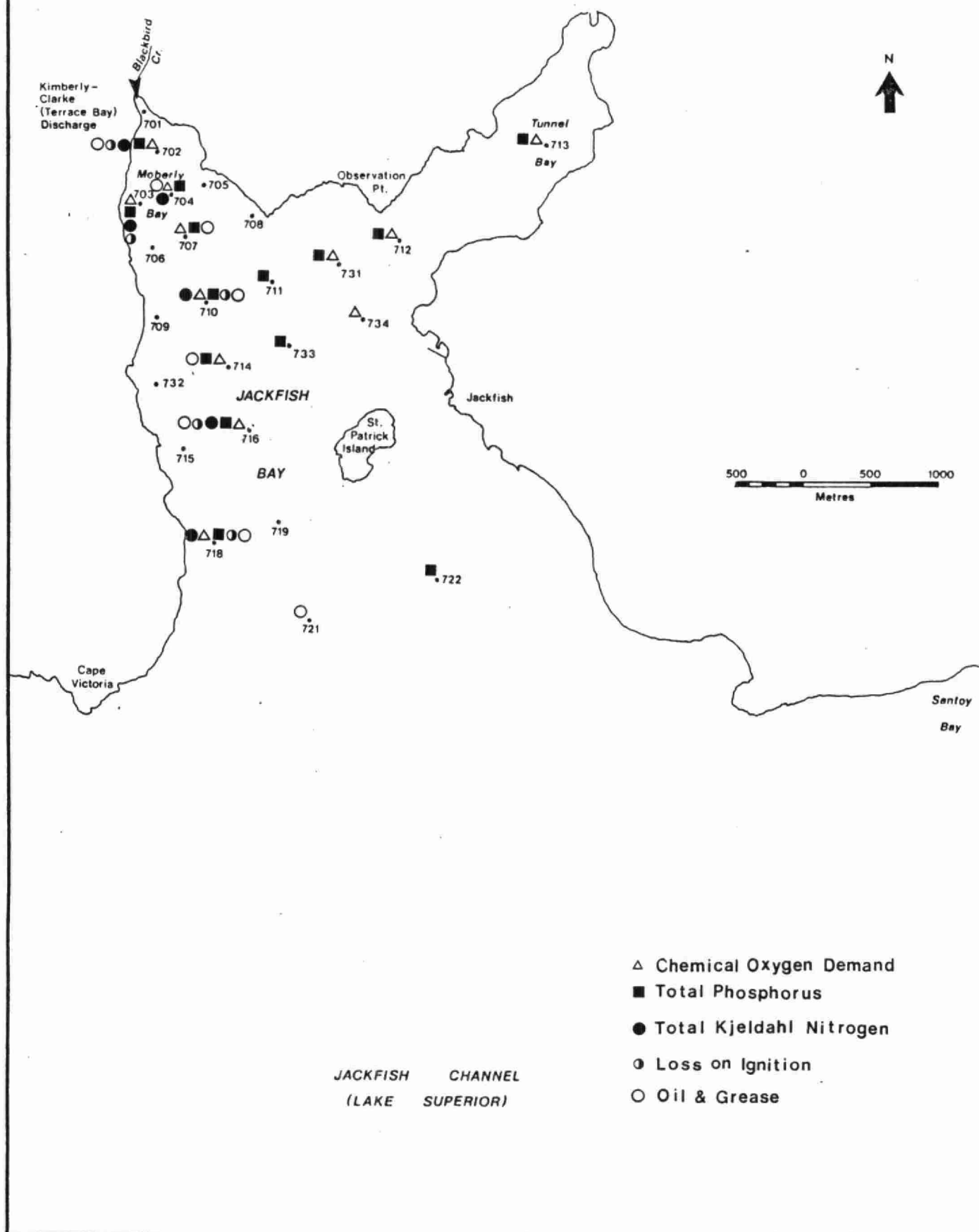


Figure 7: Locations Where Physical and Chemical Parameters in the Sediment Exceeded Disposal Guidelines

TABLE 13

The Correlation Coefficients (Loadings) Between
the First Two Principal Components and the
Original Parameters

	<u>Component 1</u>	<u>Component 2</u>
Mercury	.71	.52
Copper	.98	.08
Nickel	.92	-.22
Zinc	.92	.33
Cadmium	.80	.53
Cobalt	.91	-.13
Chromium	.59	-.45
Lead	.91	.21
Iron	.83	-.33
Manganese	.79	-.39
Aluminum	.91	.03
pH	-.19	-.80
COD	.87	.46
TKN	.86	.41
TP	.77	-.41
Volatile Solids	.89	.37
TC	.93	.18
TS	.57	.69
Gravel	-.82	.18
Very Coarse Sand	-.84	.36
Coarse Sand	-.88	.39
Medium Sand	-.84	.16
Fine Sand	-.15	-.56
Very Fine Sand	.67	-.54
Silt	.91	-.31
Clay	.83	-.27
<hr/>		<hr/>
Total Variance	65%	16.1%

nickel and coarse sand, the patterns were reverse, i.e. where nickel concentrations were high, the percentage of coarse sand is low. The spatial patterns in the parameters with high correlations (both positive and negative) are represented by the station component scores in Figure 8. The station scores on component 1 can be considered as an overall index of the sediment type, metal concentration and other chemical characteristics. Stations with high scores generally had a high proportion of silt and clay in their sediments and high concentrations of metals, except chromium. The spatial pattern of chromium was not strongly related to component 1. The chemical oxygen demand, volatile solids, phosphorus concentrations and total Kjeldhal nitrogen concentrations were also generally high at stations with high scores on component 1. The stations with low scores were characterized by sediments which consisted predominantly of coarse particles and which were relatively clean. Figure 8 illustrates that coarse clean sediments lie along the west coast of Jackfish Bay and in a band along the north shore from Blackbird Creek to the vicinity of St. Patrick Island.

The second component extracted accounted for 16% of the variance present in the original data. The two parameters which were most highly correlated with this component were pH (-0.8) and total sulphur (0.69). The component scores for the stations are shown in Figure 9. Stations with positive scores had low pH and high total sulphur concentrations and were located in the eastern portion of Jackfish Bay. Interestingly, these stations were not characterized by a particular sediment type.

Each remaining component extracted accounted for less than 6% of the total variance. They are not shown since they were not easily interpretable.

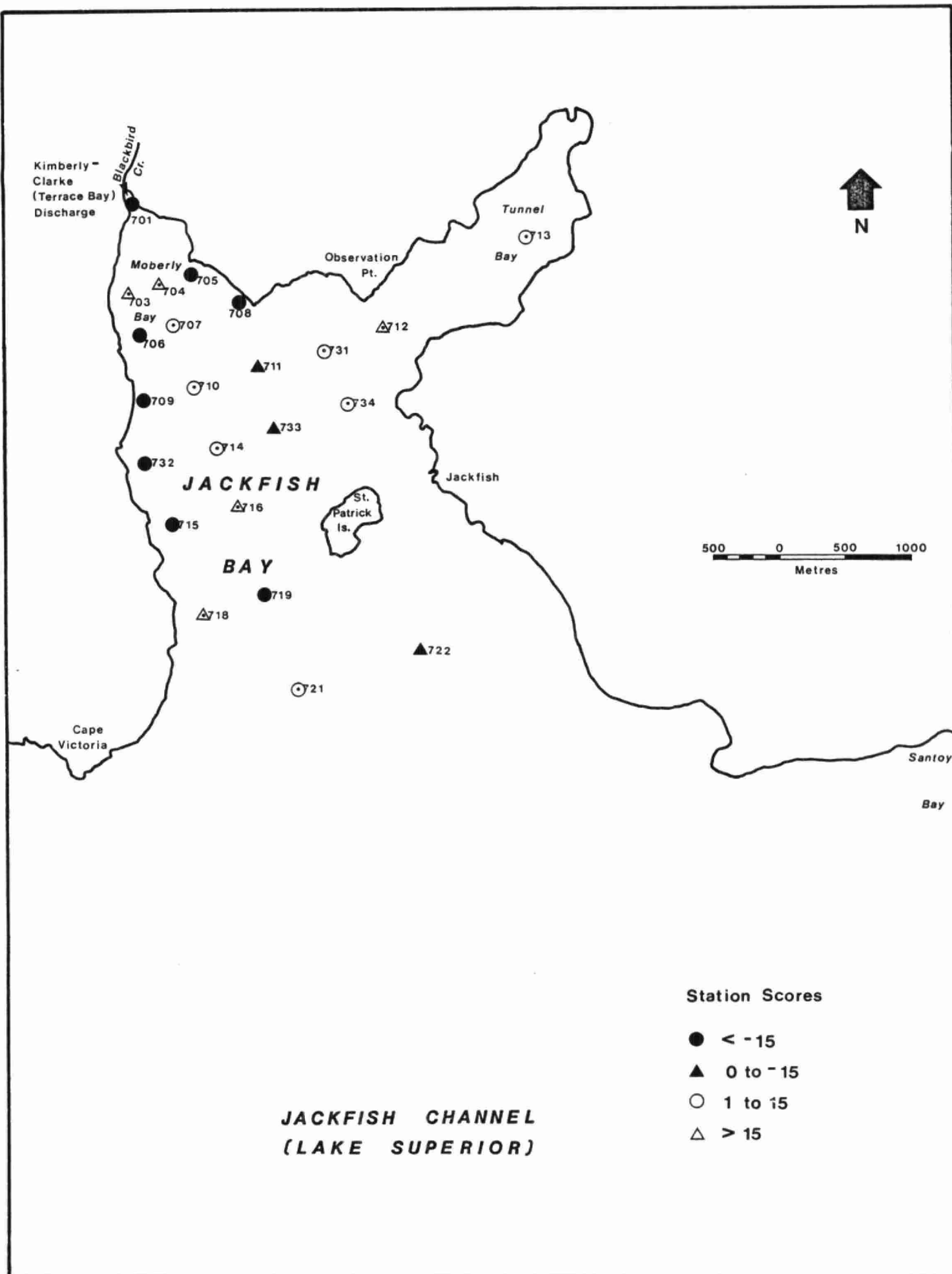


Figure 8: Station Scores on the First Component

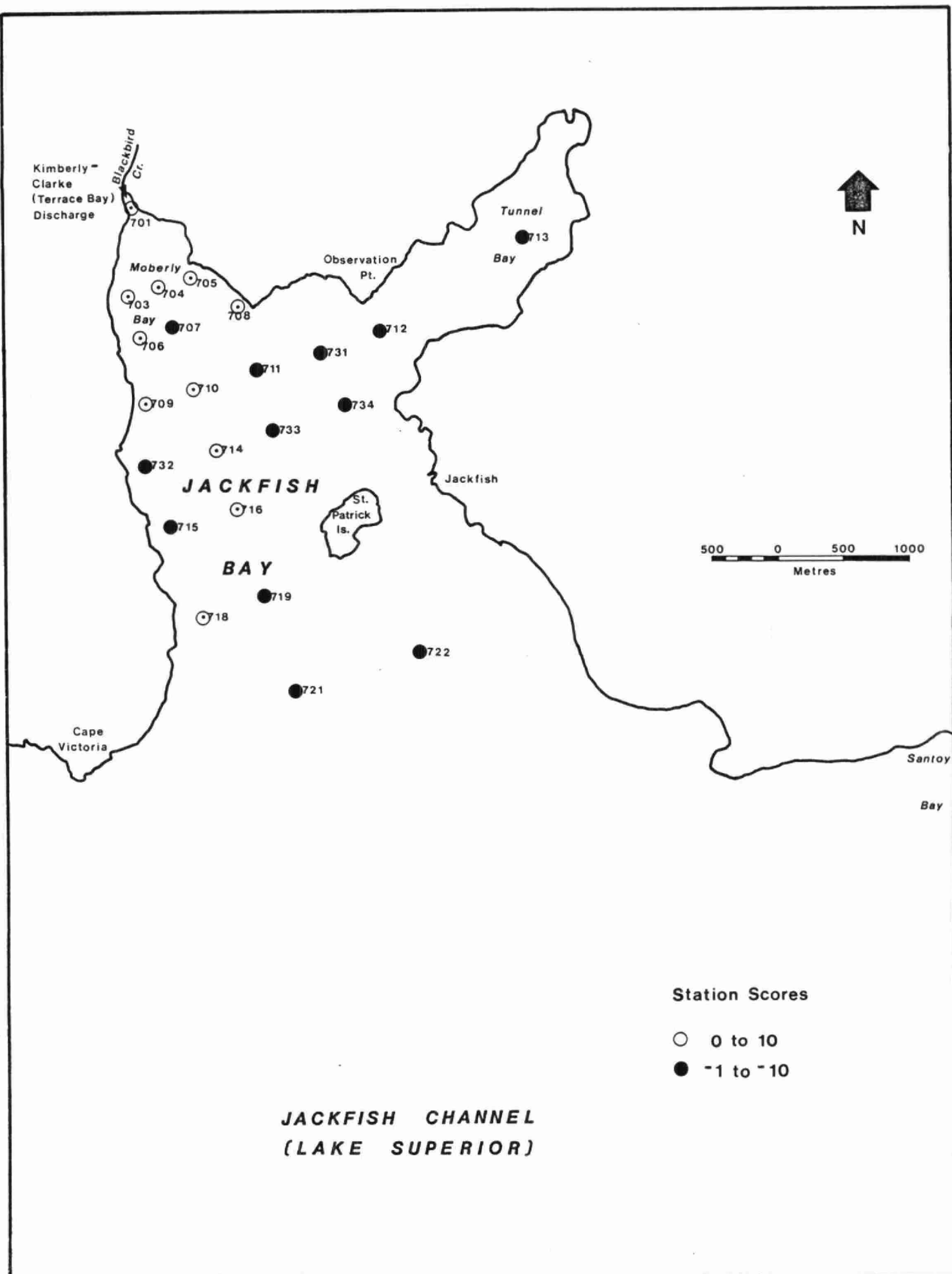


Figure 9: Station Scores on the Second Component

Prior to 1981, the most recent sediment survey was conducted in 1973 at a limited number of stations. Sampling locations in 1981 which were as close as possible to those done in 1973 were selected for comparison. The data are shown in Table 14. There is no parameter for which all values in 1981 were less than the corresponding values in 1973. Mercury, lead and chromium, however, were lower at five of the six sampling locations in 1981 suggesting some improvement. However, the comparison is weak. The principal components analysis detected high correlations between sediment type and the concentration of most contaminants and illustrated the lack of a distinct trend in either sediment type or the concentration of most contaminants with distance from the mouth of Blackbird Creek. This emphasizes the importance of incorporating sediment type rather than distance from Blackbird Creek as a factor for selecting stations on which to base year-to-year comparisons. The differences between 1973 and 1981 could simply reflect differences in sediment type.

b) Organic Contaminants

Organic contaminants were sampled at only a few locations in Jackfish Bay (Table 15). Most of the compounds detected were found at only one or two locations at levels that were close to the detection limits. Exceptions to this general trend included PCBs, phenol and guaiacol. Disposal Guidelines exist only for PCBs and these were exceeded at almost half the locations sampled. PCBs are important because they are toxic, they bioaccumulate and resist biodegradation (Callahan et al 1979). However, the toxicological significance and bioaccumulation potential of the concentrations found in Jackfish Bay sediments cannot be assessed, as a direct relationship between concentrations in the sediment and in biota has yet to be demonstrated (see for example, Elder and Mattraw 1984). Similarly, the ecological significance of the phenol and guaiacol levels in the sediment is unknown largely because of lack of data concerning their transport and fate in aquatic environments (see for example, Callahan et al 1979).

TABLE 14

Comparison of 1973 Sediment Chemistry
With 1981 Sediment Chemistry

Mercury mg/kg		Loss on Ignition %		Lead mg/kg		Zinc mg/kg	
<u>1973</u>	<u>1981</u>	<u>1973</u>	<u>1981</u>	<u>1973</u>	<u>1981</u>	<u>1973</u>	<u>1981</u>
0.256	0.01	6.0	0.9	13.6	3.0	61	35
0.746	0.17	15.0	46.0	26.0	8.7	134	140
0.127	0.07	4.5	4.1	14.3	5.0	64.3	62
0.421	0.15	7.7	5.7	39.6	17.0	92.6	77
0.094	0.27	3.1	8.5	14.4	24.0	59.3	100
0.027	0.01	0.9	0.6	14.7	3.0	48.6	22

Chromium mg/kg		Total P mg/kg		Total N mg/kg		COD mg/kg	
<u>1973</u>	<u>1981</u>	<u>1973</u>	<u>1981</u>	<u>1973</u>	<u>1981</u>	<u>1973</u>	<u>1981</u>
36.6	16	0.74	0.50	1.3	0.2	95	18
66.8	43	0.84	1.10	3.5	7.7	220	890
37.9	36	0.82	0.90	1.1	0.9	67	76
73.5	41	0.97	1.0	2.5	1.4	110	97
42.7	50	1.30	1.0	0.97	2.3	34	160
61.9	21	0.98	0.80	0.5	0.2	6.5	7.4

TABLE 15

Concentrations (ng/g) of Organic Compounds Detected in Jackfish Bay Sediments

Station Number	PCBs	HCB	-BHC	Heptachlor epoxide	Heptachlor	Endrin	Dieldrin	o,p-DDT	-Chlordane	-Chlordane	Oxychlordane	Thiodan I	Phenol	Guaiacol
701	-	-	-	-	-	-	-	-	-	-	-	-	ND	ND
702	930*	2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	7370	16 500
704	485*	31	ND	8	ND	ND	ND	ND	ND	ND	ND	ND	9980	10 520
707	70*	2	ND	ND	2	ND	ND	ND	ND	ND	ND	ND	510	380
709	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	-	-
710	105*	2	1	ND	2	14	ND	ND	ND	11	3	5	320	310
711	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
714	110*	1	2	ND	1	6	ND	ND	ND	ND	ND	ND	630	510
715	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	-	-
716	155*	7	2	ND	ND	4	2	5	2	6	6	3	-	-
718	105*	2	3	ND	ND	ND	ND	ND	3	4	4	3	-	-
719	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	-	-
722	45*	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Detection Limit	20	1	1	1	1	4	2	5	2	2	2	2	250	250

* indicates level at or above MOE Dredging Guideline (50 ppb) for open water disposal of spoils.

- no sample

ND - not detected

APPENDIX 1

PHYSICAL, CHEMICAL AND BIOLOGICAL PARAMETERS INCLUDED IN THE ANALYSES OF WATER SAMPLES FROM JACKFISH BAY AND BLACKBIRD CREEK

- 1981 -

Dissolved Organic Carbon (DOC)
Chemical Oxygen Demand (COD)
Biological Oxygen Demand (BOD₅)
Conductivity
Suspended Solids
Colour
Turbidity
Tannins
Lignins
Sulphate
pH
Temperature
Dissolved Oxygen (DO)
Reactive Phenolics

Trace Metals

Mercury
Arsenic
Cadmium
Copper
Nickel
Lead
Zinc

Bacteria

Fecal Coliforms
Heterotrophs
Sulphate Reducers

Phenolic Compounds

Phenol
Homovanillic acid
Vanillin
Guaiacol
Acetovanillin
Syringaldehyde
Acetosyringone
p-cresol
o-chlorophenol
p-chlorophenol
m-chloro-p-cresol
2,4-dichlorophenol
2,3,4-trichlorophenol
2,4,5-trichlorophenol
2,3,4,5-tetrachlorophenol
2,3,5,6-tetrachlorophenol
pentachlorophenol

Fatty Acids

- Capric
- Lauric
- Myristic
- Palmetic
- Stearic
- Oleic
- Linoleic
- Linolenic
- Arachidic

Aromatic Acids

- Benzoic
- Salicylic
- Phthalic

Resin Acids

- Pimaric
- Sandaracopimaric
- Levopimaric
- Isopimaric
- Neobietic
- Abietic
- Dehydroabietic

Polychlorinated Biphenyls (PCBs) and Organochlorine Pesticides

- PCBs total
- hexachlorobenzene
 - Benzene hexachloride (BHC)
 - BHC
 - BHC (lindane)
- heptachlor
- heptachlor epoxide
- endrin
- aldrin
- dieldrin
- pp-DDE
- op-DDT
- pp-DDD
- pp-DDT
 - chlordane
 - chlordane
- oxychlordane
- mirex
- DMDT-methoxychlor
- endosulphan 1
- endosulphan 2
- endosulphan sulphate

Organohalides

- Chloroform
- Carbontetrachloride
- Trichloroethylene
- Tetrachloroethylene
- Bromodichloromethane

APPENDIX 2

PARAMETERS MEASURED IN SEDIMENT SAMPLES COLLECTED FROM JACKFISH BAY

- 1981 -

Particle Size Distribution

pH
Chemical Oxygen Demand (COD)
Total Kjeldahl Nitrogen (TKN)
Total Phosphorus (TP)
Oil and Grease
Volatile Solids
Total Carbon (TC)
Total Sulphur (TS)
Sulphides
Reducible Sulphur

Heavy Metals

Mercury
Copper
Nickel
Zinc
Cadmium
Cobalt
Chromium
Lead
Iron
Manganese
Aluminum

PCBs and Organochlorine Pesticides

PCB
Hexachlorobenzene (HCB)
-BHC
-BHC
-BHC (Lendane)
Heptachlor
Heptachlor epoxide
Endrin
Aldrin
Dieldrin
p,p-DDE
o,p-DDT
p,p-DDD
p,p-DDT
-chlordane
-chlordane
oxychlordane
Mirex
DMDT-methoxychlor
Thiodan I
Thiodan II
Endosulphan sulphate

Phenolic Compounds

Phenol
Homovanillic acid
Vanilline
Guaiacol
Acetovanillone
Syringaldehyde
Acetosyringone
p-cresol
o-chlorophenol
p-chlorophenol
m-chloro-p-cresol
2,4-dichlorophenol
2,4,5-trichlorophenol
2,3,4,5-tetrachlorophenol
2,3,5,6-tetrachlorophenol
Pentachlorophenol

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DATE DUE		

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Kirby, Mary

Effect of discharges

from Kimberly -

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